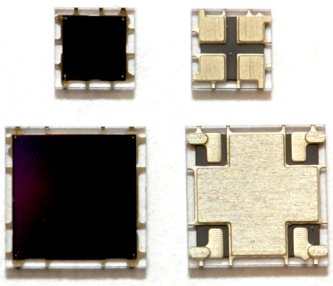
B-Series: Fast, Blue-Sensitive Silicon Photomultiplier Sensors



B-series Silicon Photomultipliers (SiPM) offer the highest PDE, UV sensitivity and are available with SensL's proprietary fast mode output. Three sensor sizes are available; 1mm, 3mm and 6mm packaged in a variety of formats including TO-can, ceramic header and 4-side tileable surface mount technology (SMT) package. In addition, two evaluation boards are available with pre-mounted SMT sensors to facilitate rapid product evaluation. Arrays of SMT devices are also available in sizes from 16 to 144 pixels.

This User Manual covers all aspects of using and understanding the B-Series range of sensors and evaluation boards. More details on the performance characteristics of the B-Series sensors can be found in the B-Series datasheet.

Overview

The B-Series SiPM sensors from SensL are based on a P-on-N diode structure (Figure 1) that results in a high PDE (Photon Detection Efficiency) and sensitivity into the UV.

All B-Series SiPM sensors also feature SensL's proprietary *fast output* terminal (Figure 2), giving access to signals with extremely fast rise times and short pulse widths.

B-Series SiPM products are available in either MicroSB (2-pin) or MicroFB (3-pin) versions.

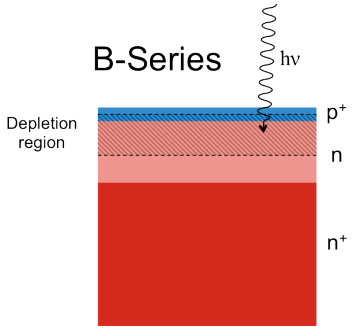


Figure 1, P-on-N sensor structure

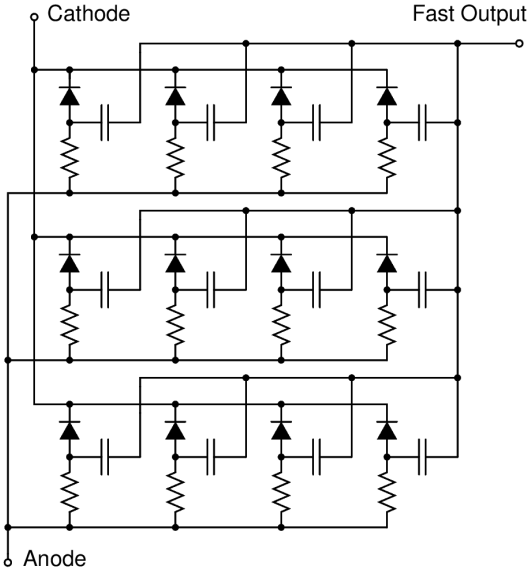


Figure 2, Simplified microcell level schematic of the B-Series SiPM.

MicroSB

Although all B-series SiPM sensors have the architecture shown in Figure 2, MicroSB packaged products only have two pins giving access to the *anode* and *cathode*. The *fast output* is **not** accessible in MicroSB products.

MicroFB

MicroFB packaged products have three (or more) pins, giving access to the *fast output* as well as the *anode* and *cathode*. The *fast output* is the derivative of the internal fast switching of the microcell in response to the detection of a single photon.

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Glossary

B-Series - A family of SiPM products based upon a P-on-N structure, featuring sensitivity into the UV.

FB - B-Series SiPM product that has at least 3 pins (or pads) accessible that include *anode*, *cathode* and the *fast output* and can therefore be used in *fast mode* configuration.

SB - B-Series SiPM product that has only 2-pins accessible, giving access to the *anode* and *cathode*. The third terminal (fast output) is not accessible, and so SB sensors can only work in *standard mode*.

Fast mode - Using the *fast output* signal from an FB product for improved timing or photon counting applications.

Standard mode - Using the signal from the *anode* and *cathode* for the readout of an SB or FB product where timing performance is less critical.

Biasing and Readout

Fast Mode Biasing and Readout of MicroFB Sensors

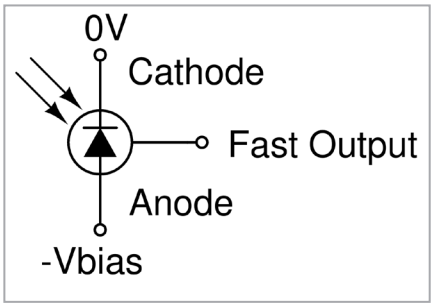


Figure 3, Recommended biasing

Recommended Fast Mode Biasing

The fast output is referenced to the *cathode* (substrate) of the SiPM. Therefore the use of a negative bias voltage applied to the *anode* with *cathode* at 0V is recommended, as in Figure 3. The *fast mode* signal polarity is positive. (If an application requires the use of a positive bias, refer to the advice in Appendix A.) Please refer to the B-Series datasheet for operating over-voltage range.

The observed signals will be very fast, with rise-times ranging from 300ps to 1ns and pulse widths of 600ps - 3ns (depending on sensor size). A typical output pulse for a 3mm sensor (MicroFB-30035) is shown in Figure 4.

For all application circuits shown in this User Manual, it is recommended that a bias voltage filter, such as the one shown in Figure 5, is used.

Alternative biasing schemes are discussed in Appendix A.

Recommended Fast Mode Readout

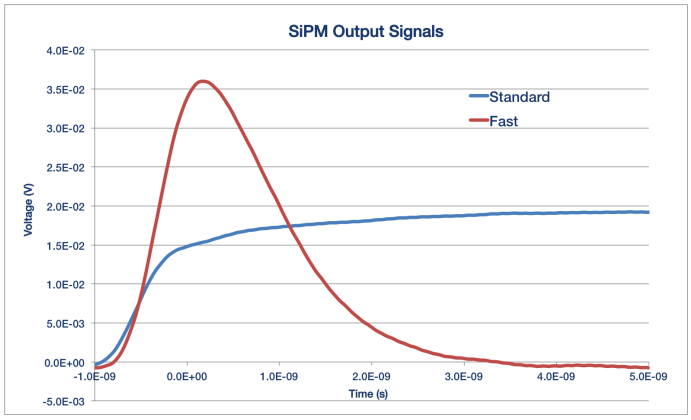


Figure 4, Fast mode output (red) of a MicroFB-SMA-30035 when illuminated with a 40ps laser pulse (Photek LPG-405). ~2.5% of microcells are fired in this pulse. Also shown is part of the standard output pulse, which is shown in full in Figure 9. Scope input = 50Ω.

Due to the extreme speed of the signals from the *fast output*, care should be taken in the routing of the signal. Common microwave/RF design rules, such as controlled impedance microstrip lines, should be used. The capacitance of the fast output electrode is much lower (of the order of 2-3pF for a 1mm device) than in a standard configuration. The lower output capacitance does not typically allow the use of a transimpedance amplifier, and instead one can use an RF style (50Ω impedance) solution including direct connection to a coaxial cable. The 3mm and 6mm devices have higher capacitance, so for best operation when connecting to an oscilloscope or driving long wires, it is recommended that the fast output be connected to an RF transformer such as the RFXF9503 as in Figure 7. This provides impedance matching, to improve amplitude and timing characteristics of the pulse for 50Ω impedance. For 1mm devices the capacitance is low enough to allow direct 50Ω connection as in Figure 6. Another feature of the *fast output* electrode is that it is AC-coupled, with no DC component. However, if needed, one can combine it with the standard output (see the next section) of the SiPM to incorporate DC information.

Fast Output Amplification

It is important to note that the signal charge injected into the fast output electrode is typically about 2% of the SiPM charge generated during the avalanche. However, the pulse duration is approximately 100 times shorter, so the current amplitude observed is about 0.02*100 = 2 times higher. This high current amplitude, in combination with the significantly lower output capacitance, make the device suitable for photon counting at very high speed (tens of MHz and higher has been demonstrated in the lab).

For amplification of the fast signal it is recommended that a low noise 50Ω RF amplifier be used. As with standard readout, the level of gain required is dependent on the application. For applications with high photon counts it is recommended that the Mini-Circuits ZX60-43S+ be used. For photon counting applications it is recommended that the Mini-Circuits ZFL-1000LN+ be used. For PET applications it is possible to obtain both timing and energy resolution information from the fast output, with the anode and cathode only used for biasing.

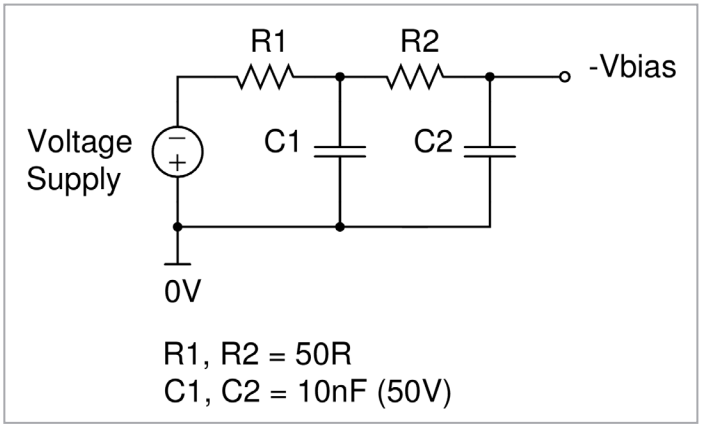


Figure 5, Generic biasing filter, recommended for all circuits given in this User Manual.

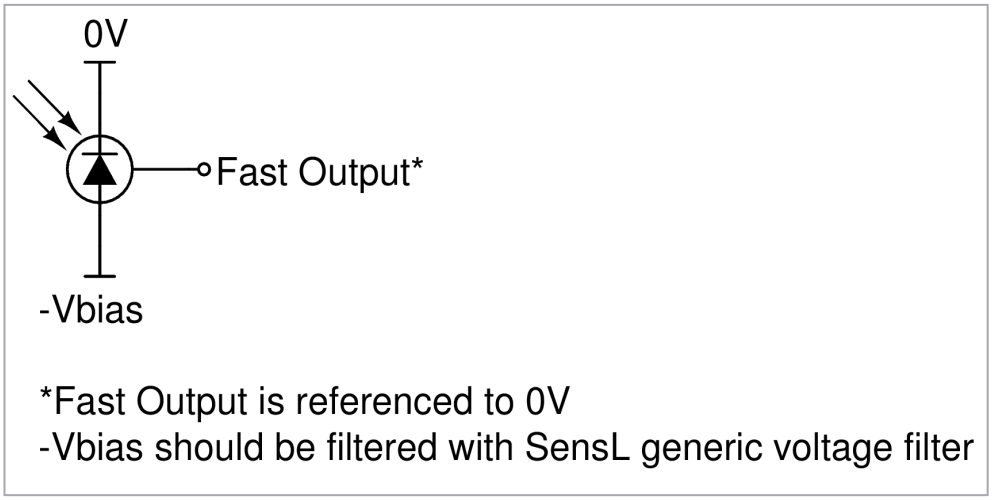


Figure 6, Recommended fast SiPM readout circuitry for 1mm MicroFB sensors.

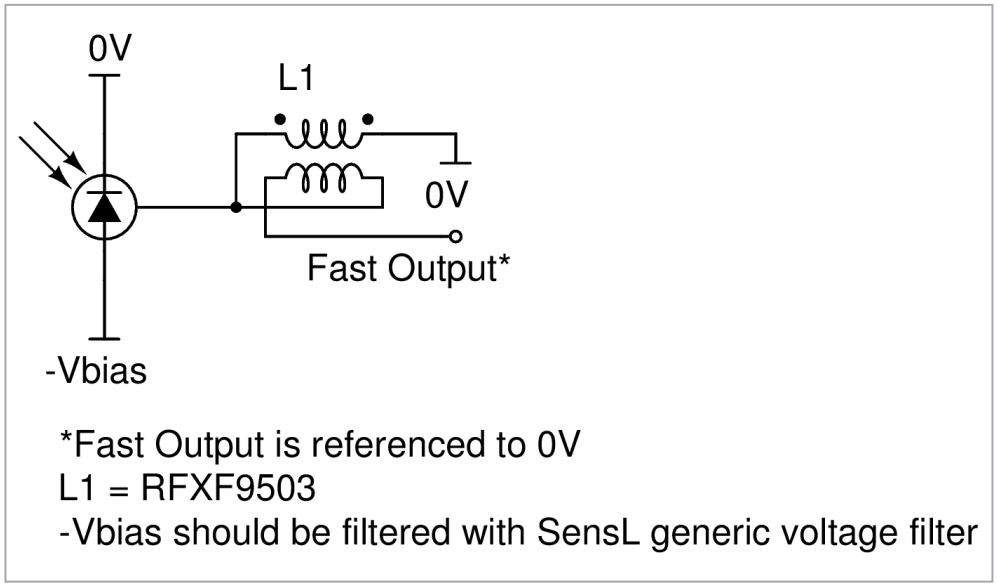


Figure 7, Recommended fast SiPM readout circuitry for 3mm and 6mm MicroFB sensors. Also shown is the recommended transformer part number and pin-out labelling.

Standard Mode Biasing and Readout of B-Series Sensors

For applications that do not require fast timing from the MicroFB, or for the MicroSB products that do not give access to the *fast output* signal, SensL's B-Series sensors will perform as a conventional SiPM. For MicroFB products the *fast output* terminal can be left open with no detriment to its *standard mode* performance. Standard mode signals may be more suitable for applications involving slow pulses or slowly-varying, continuous light levels, such as in luminometers or for gamma-ray spectroscopy with slow or low-light scintillators.

Recommended Standard Mode Biasing

Figure 8 below shows the *standard mode* biasing configuration. For MicroFB sensors the *fast output* electrode is left open (unconnected). For all B-series sensors read out in standard mode, the cathode should be held at a positive bias with reference to the anode. It is recommended that the signal is taken from the side of the sensor held at 0V. Reading out in this way yields a pulse that has a rise time of 1ns-10ns and a decay time of several hundred ns (depending on sensor and microcell size). A typical standard mode output pulse shape is shown in Figure 9. Alternative biasing schemes are discussed in Appendix A.

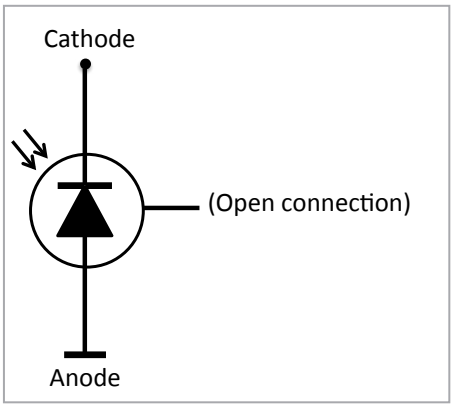


Figure 8, Biasing for standard mode. The cathode should be positive with respect to the anode, but either a positive or negative bias can be used.

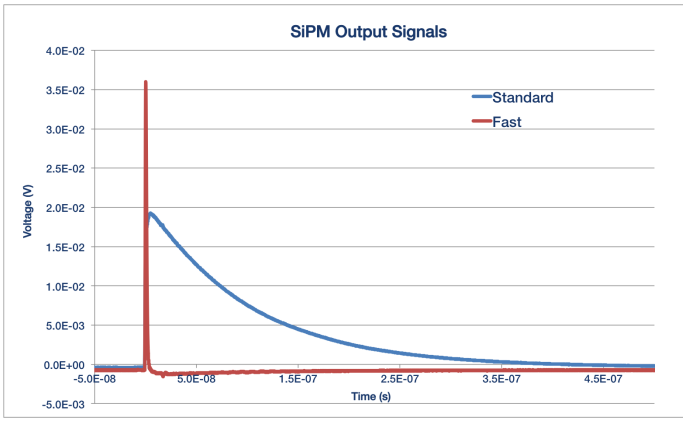


Figure 9, Standard output signal (blue) from a MicroFB-SMA-30035 when illuminated with a 40ps laser pulse (Photek LPG-405). ~2.5% of microcells are fired in this pulse. Also shown is the fast output (red) from the same pulse. Scope input = 50Ω.

When the *fast output* is not in use it should be left floating. Do not connect it to ground or have any wires or cables connected to it.

Recommended Standard Mode Readout and Amplification

Figure 10 shows how the B-Series devices can be connected to a standard high speed amplifier, such as the OPA656, to convert the standard mode output signal current to a voltage. This technique is recommended for standard mode readout of all SensL SiPM devices. In the case of MicroFB devices the fast output can be left open.

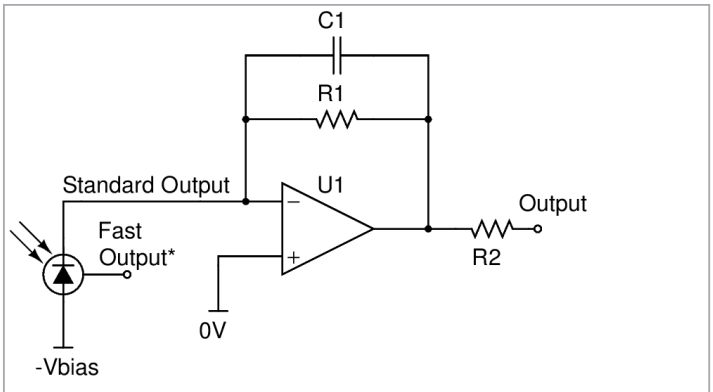
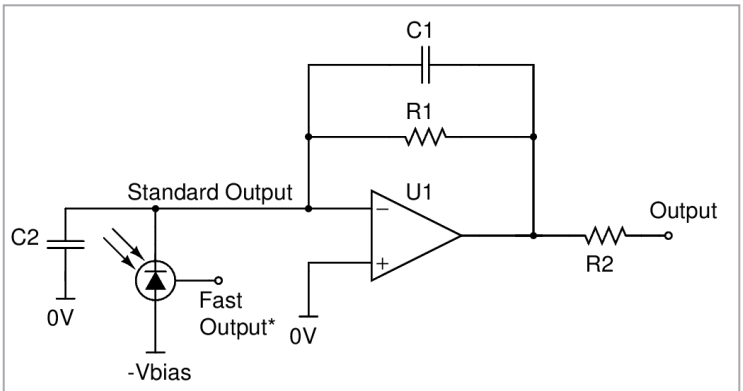


Figure 10, Example readout circuit for standard mode.

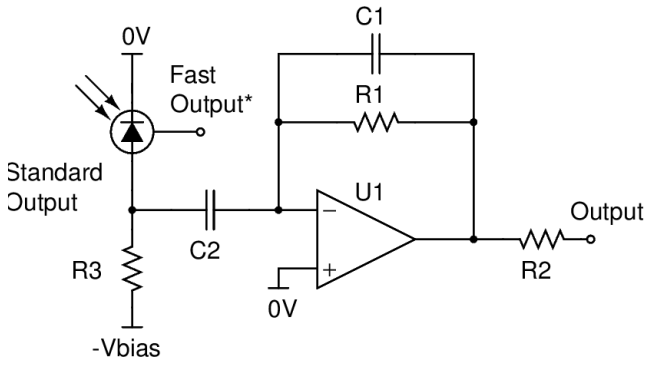
Dual Mode Readout of MicroFB Sensors

It is possible to read out both *fast* and *standard outputs* simultaneously from the sensor to obtain two separate signals. This can be used for obtaining timing (*fast output*) and amplitude information (*standard output*) from separate channels. This could be useful for applications such as PET (Positron Emission Tomography) where timing and energy information are required from each photon pulse. Note that this is only possible with MicroFB sensors. AC and DC coupled options for connecting the device for dual readout are shown in Figures 11 and 12.



*Fast Output is referenced to 0V
R1 = 2K2 (1mm sensor) or 470R (3mm or 6mm sensor)
R2 = 50R
C1 = 3pF
C2 = 100pF (only required if also using Fast Output)
U1 = OPA656
Fast Output readout options:
1) Transformer RFXF9503 (large signal to oscilloscope)
2) Minicircuits Amplifier ZX60-43+ (large signal)
3) Minicircuits Amplifier ZFL-1000LN+ (small signal)
-Vbias should be filtered with SensL generic voltage filter

Figure 11, DC coupled readout option. The standard output is amplified through a transimpedance amplifier (TIA).



*Fast Output is referenced to 0V
R1 = 2K2 (1mm sensor) or 470R (3mm or 6mm sensor)
R2 = 50R
R3 = 1K
C1 = 3pF (50V)
C2 = 10nF (50V)
U1 = OPA656
Fast Output readout options:
1) Balun transformer RFXF9503 (large signal to oscilloscope)
2) Minicircuits amplifier ZX60-43+ (large signal)
3) Minicircuits amplifier ZFL-1000LN+ (small signal)
-Vbias should be filtered with SensL generic bias filter

Figure 12, AC coupled readout option. DC information from the SiPM is lost but the pulse amplitude is maintained through the transimpedance amplifier (TIA).

A third option for simultaneous readout of the standard and fast outputs provides a DC coupled standard output signal, and preserves the ability to read out the fast output. The decoupling capacitor from the cathode to 0V is critical to provide a return path for the fast output. This circuit is used on the SensL -SMA and -SMTPA evaluation boards. SensL recommend the -Vbias readout options from Figures 11 and 12 for most system designs. Alternative biasing schemes are discussed in Appendix A.

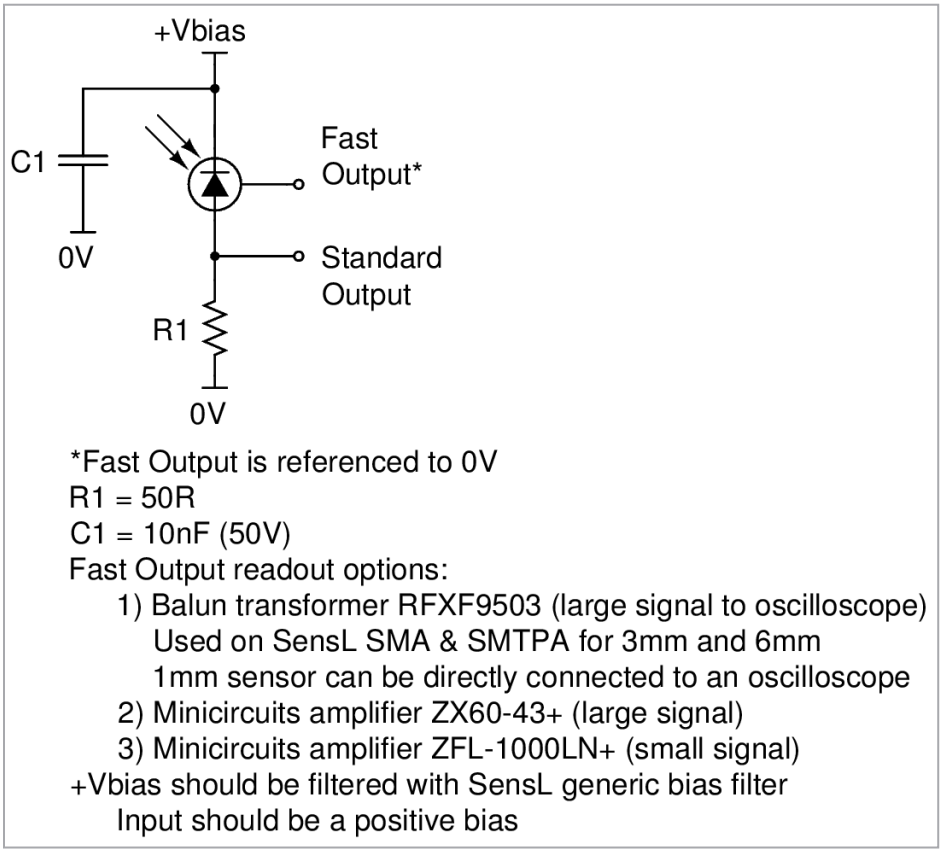

+Vbias
C1
0V
Fast
Output*
Standard
Output
R1
0V
*Fast Output is referenced to 0V
R1 = 50R
C1 = 10nF (50V)
Fast Output readout options:
1) Balun transformer RFXF9503 (large signal to oscilloscope)
Used on SensL SMA & SMTPA for 3mm and 6mm
1mm sensor can be directly connected to an oscilloscope
2) Minicircuits amplifier ZX60-43+ (large signal)
3) Minicircuits amplifier ZFL-1000LN+ (small signal)
+Vbias should be filtered with SensL generic bias filter
Input should be a positive bias

Figure 13, Third option for dual readout that is employed on the SensL -SMA and -SMTPA evaluation boards. Further information on using a positive bias is given in Appendix A.

Readout of Arrays of SiPM Devices

Many applications require the use of multiple sensors in the form of an array, such as the SensL Array-SMT line of products. Large arrays can pose a readout challenge due to the many channels of amplification and processing that are required. Therefore, methods of reducing the number of channels are often employed in order to reduce the readout requirements. Many examples of this can be found in the literature, and SensL has extensive experience in developing solutions for array readout, as demonstrated by the Matrix family of products. Please contact SensL to request a Tech Note on the subject of large area array readout.

B-Series Mounted Sensors

Some B-Series sensors are available ready mounted on test boards, to allow for easy evaluation. The -SMA and -SMTPA were designed for evaluation of fast output with a DC coupled standard output. The SMA board is configured for use with the circuit shown in Figure 13 and the SMTPA can also be configured in this way with the use of an external decoupling capacitor and sense resistor. Note that the 3mm and 6mm versions of the -SMA and -SMTPA have baluns at their fast outputs for signal shaping and impedance matching. The use of these boards is detailed in the following sections.

MicroFB-SMA

The MicroFB-SMA-XXXXX product line (Figure 14) features either an SMT or X18 packaged SiPM sensor (type specified by the XXXXX digits) soldered onto a small PCB board. The board is simple to use, having just three SMA connectors: one delivers the bias voltage (*Vbias*) and the other two provide the output signals: standard output from the anode (*Sout*) and the fast output (*Fout*). The circuitry on the board is designed to bias the sensor in such a way as to retain the optimum high-speed performance. A typical output pulse is shown in Figure 4 which was taken from a MicroFB-SMA-30035. The circuitry used is as given in Figure 13 with the addition of a bias filter (Figure 5) and transformer on the fast output of the 3mm and 6mm versions (Figure 7).

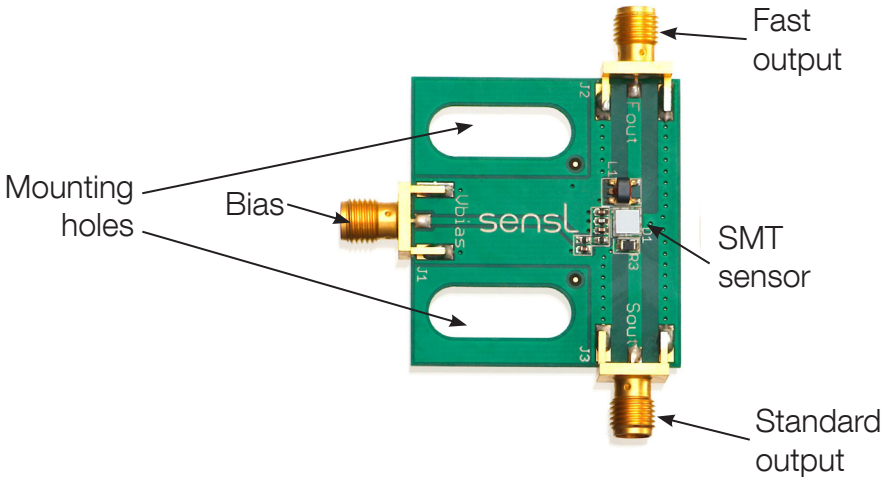


Figure 14, The MicroFB-SMA board: 3mm SMT version

Output	Function	Comments
Vbias	bias input (cathode)	positive bias input
Fout	fast output	if unused can be left open
Sout	standard output (anode)	if unused can be left open

Table 1, SMA Connections

The MicroFB-SMA is recommended for users who require a plug-and-play set-up to quickly evaluate MicroFB sensors with optimal timing performance. The board provides outputs which can be connected directly to the oscilloscope or measurement device. The board also allows the standard output from the anode to be observed at the same time as the fast output. Table 1 summarizes the connections to the SMA board. Each board has two mounting holes to allow secure placement during testing, with sensors located at the edge of the board. This allows two sensors to be placed in close proximity for coincidence timing measurements.

MicroFB-SMTPA

The MicroFB-SMTPA-XXXXX, or Pin Adapter board (Figure 15), features an SMT-packaged SiPM sensor (type specified by the XXXXX digits) mounted onto a small PCB board. The PCB has five through-hole pins that allow easy electrical connections to the electrodes of the SMT sensor. The pins are labeled on the PCB with numbers 1 - 5. Each of the numbered pins is connected as listed in Table 2, with the option to use either a positive or negative bias. Note that the positive bias configuration (see Figure 13) will provide better timing performance than the negative bias configuration.

Pin No.	Connection	Function	
		Positive bias	Negative bias
1	anode	standard output (*if unused connect to zero V*)	negative bias input
2	fast	fast output (*if unused can be left open*)	fast output (*if unused can be left open*)
3	cathode	positive bias input	standard output (*if unused connect to zero V*)
4	gnd	PCB gnd	PCB gnd
5	n/c	do not connect	do not connect

Table 2, Pin assignments for the MicroFB-SMTPA board

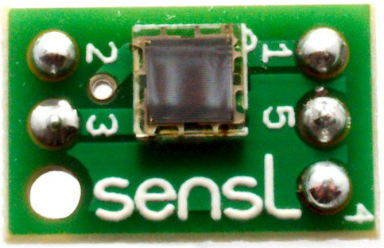


Figure 15, Pin numbering on the MicroFB-SMTPA board

The biasing circuit of the SMTPA is the same as on the SMA board (as indicated by Figure 13), however it does not contain any on-board decoupling on the bias line. Therefore, a bias filter, such as that in Figure 5, should be included on the bias line before connecting to the relevant bias input pin (see Table 2). The standard output can be connected directly to an amplifier or 50Ω load oscilloscope. If the standard output is not used, then that pin should be connected to zero Volts.

It should be noted that the presence of the pins will slightly degrade the signal from the sensor. Figure 16 shows a typical pulse from a MicroFB-SMTPA-30035.

The connectors from Samtec used are:

BBL-103-G-E

BBL-102-G-E

Compatible sockets from Samtec are:

SL-103-G-10

SL-102-G-10

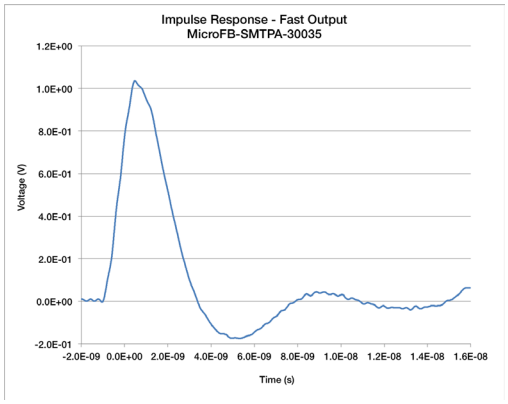
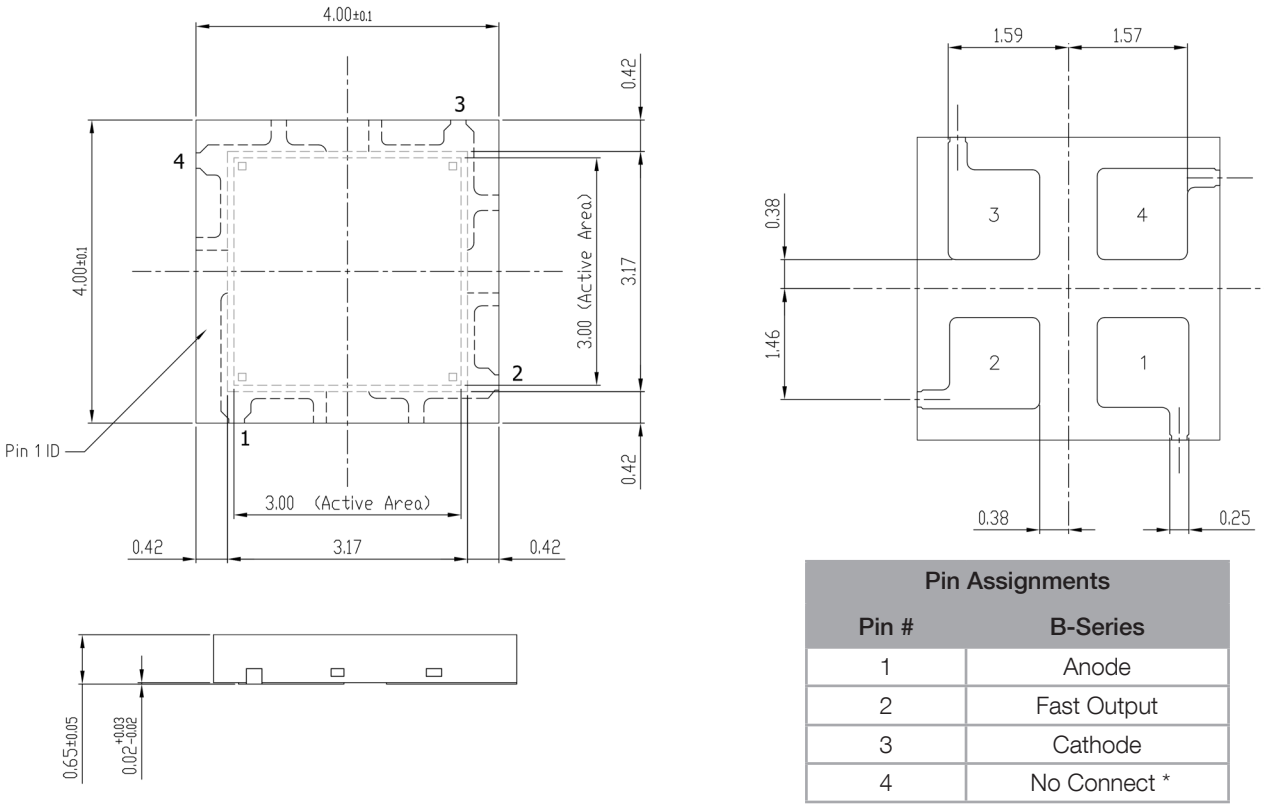


Figure 16, Typical pulse from a MicroFB-SMTPA-30035

Schematics, Pin/Pad Identification and Solder Footprint

MicroFB 30000 Series SMT Package



Pin Assignments	
Pin #	**B-Series**
1	Anode
2	Fast Output
3	Cathode
4	No Connect *

** No Contact (NC) pin 4 should be soldered to PCB, this pin can be connected to ground but it can also be left floating without affecting the dark noise.*

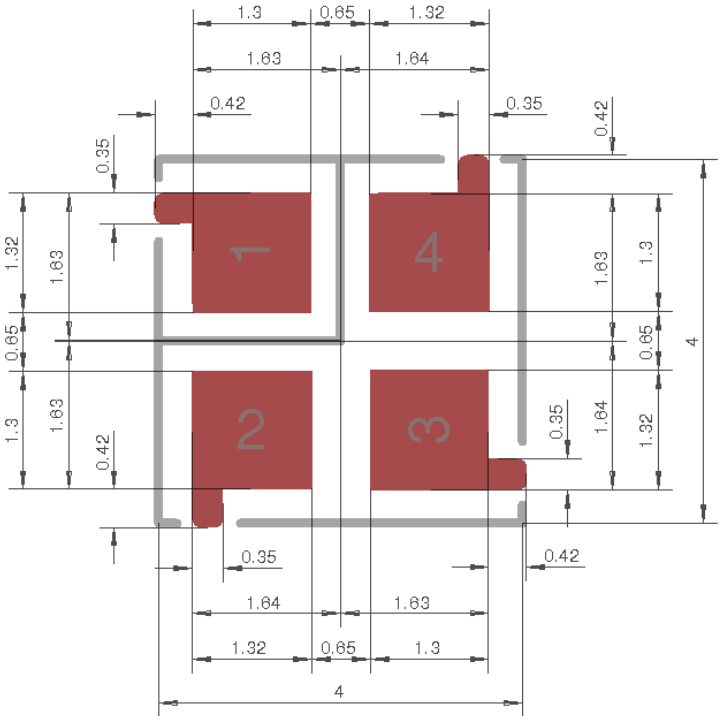
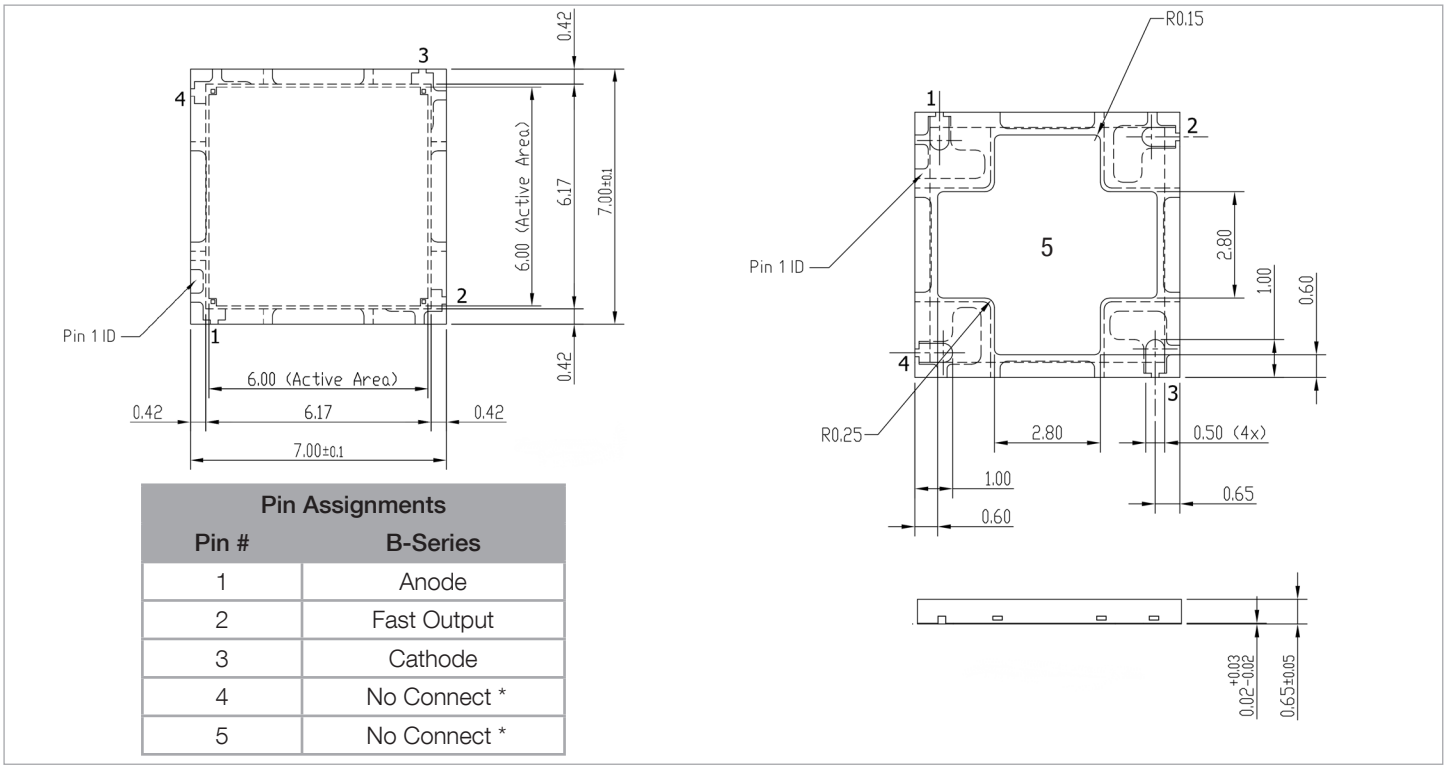


Figure 17, Solder footprint for the MicroFB-300XX-SMT part. All dimensions in mm. Fingers on pads 1-4 can be omitted in tight pitch PCB designs to better facilitate routing of signals.

Schematics, Pin/Pad Identification and Solder Footprint

MicroFB 60000 Series SMT Package



Pin Assignments	
Pin #	**B-Series**
1	Anode
2	Fast Output
3	Cathode
4	No Connect *
5	No Connect *

** No Contact (NC) pin 4 should be soldered to PCB, this pin can be connected to ground but it can also be left floating without affecting the dark noise. Recommend that NC pin 5 paddle is not soldered to the PCB and left floating to achieve optimal soldering on pins 1 to 4. Care must be taken to ensure that no electrical contacts on the PCB, such as vias, short out on the paddle if using the area underneath for routing. If it is desired to solder pin 5 to the PCB, for example to heatsink or ground the paddle, please consult your contract manufacture for their solder recommendations based on their equipment and capabilities.*

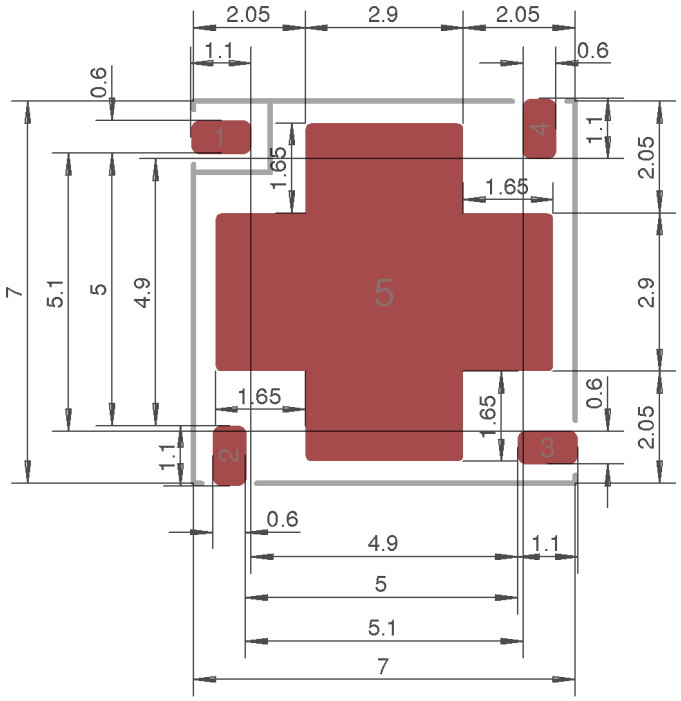
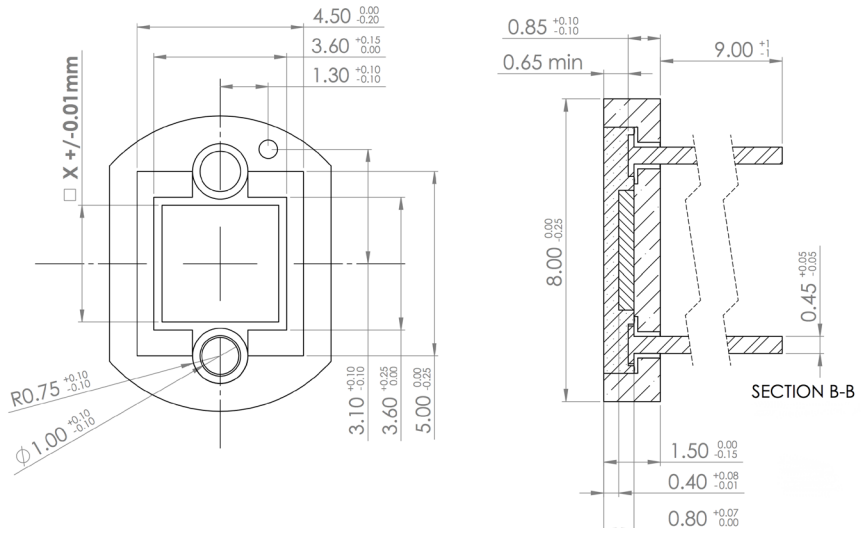


Figure 18, Solder footprint for the MicroFB-600XX-SMT part. All dimensions in mm.

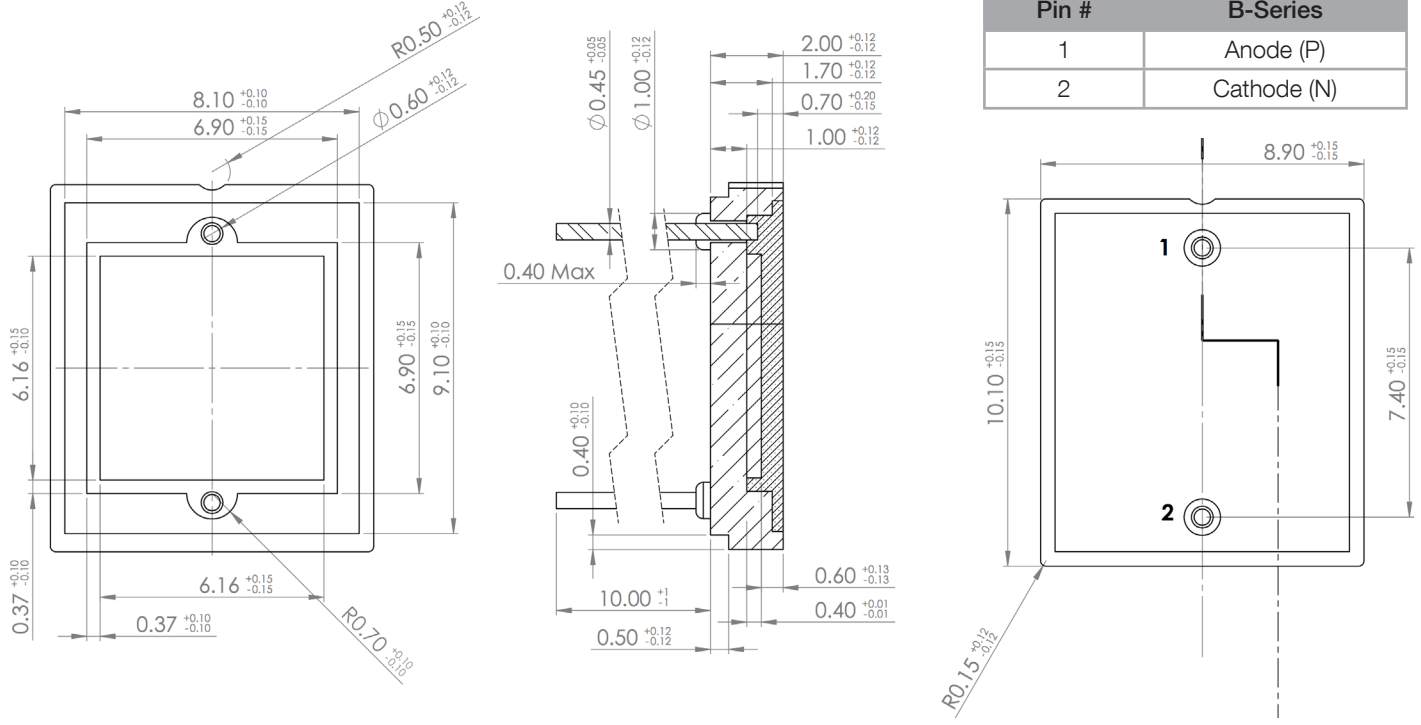
MicroSB 30000 (and 10000) Series X13 Ceramic Package

(Note 10000 series package is same but with smaller sensor size.)



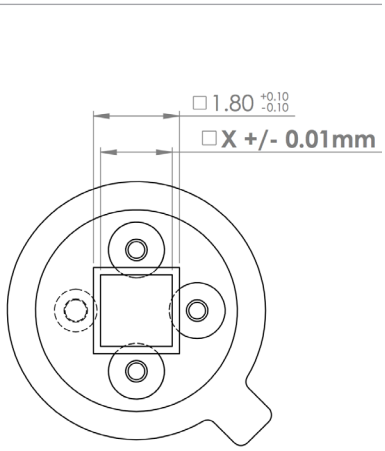
Pin Assignments	
Pin #	**B-Series**
1	Anode (P)
2	Cathode (N)

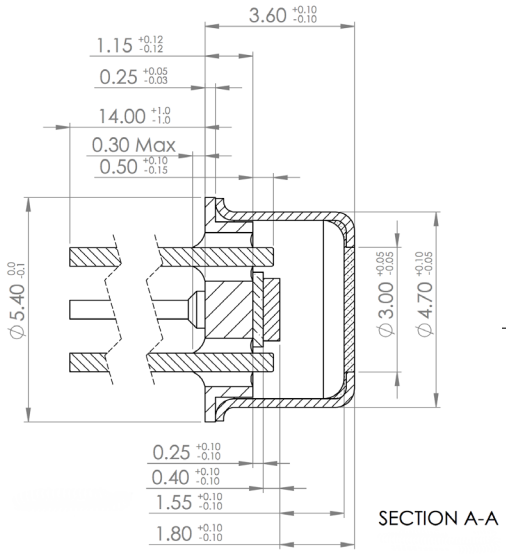
MicroSB 60000 Series X13 Ceramic Package



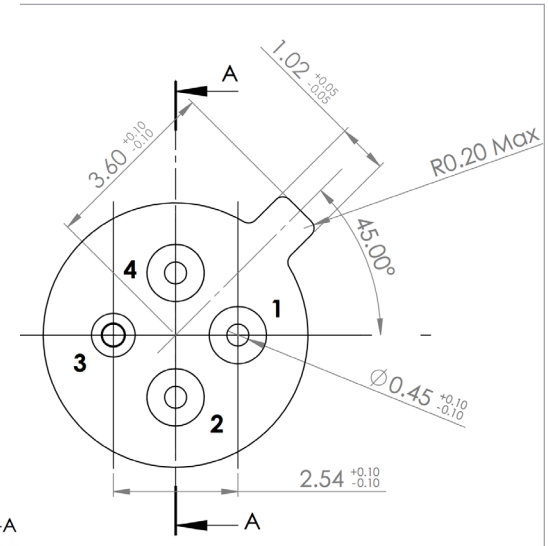
Pin Assignments	
Pin #	**B-Series**
1	Anode (P)
2	Cathode (N)

MicroFB 10000 Series X18 Package



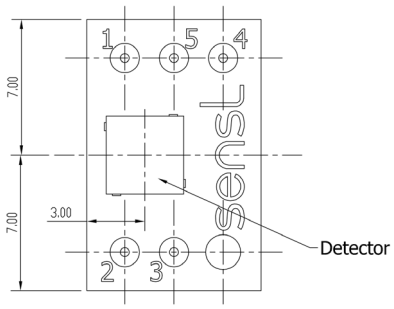


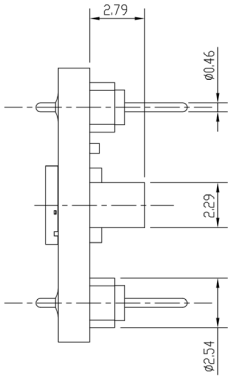
SECTION A-A

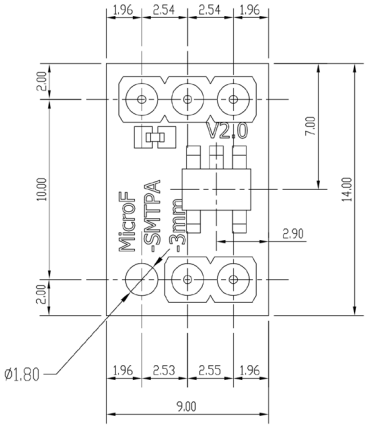


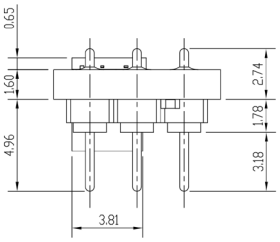
Pin Assignments	
Pin #	**B-Series**
1	Fast Output
2	Cathode (N)
3	GND
4	Anode (P)

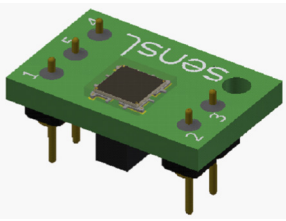
*MicroFB-SMTPA Board**





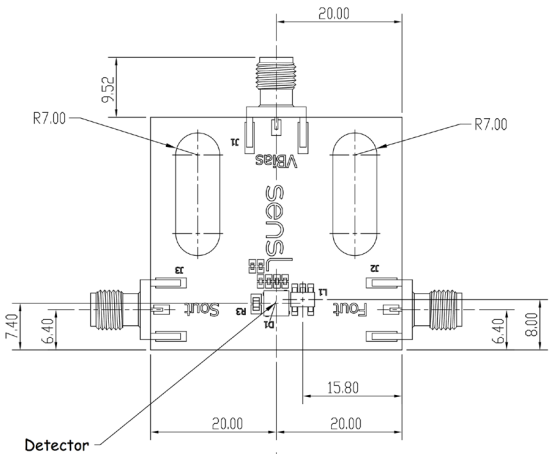


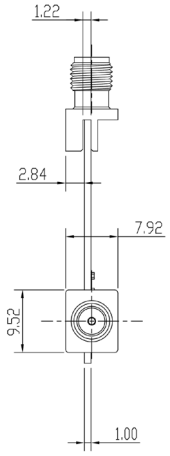


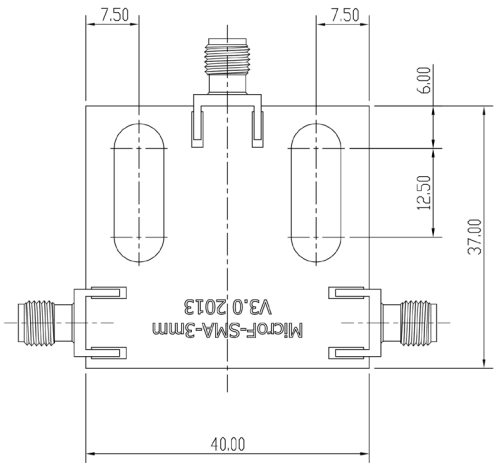


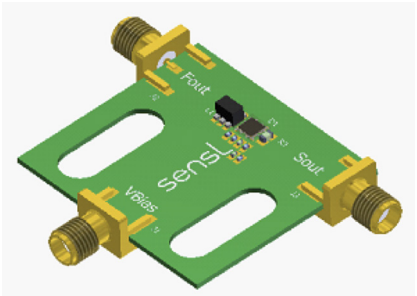
See Table 2 for pin connections.

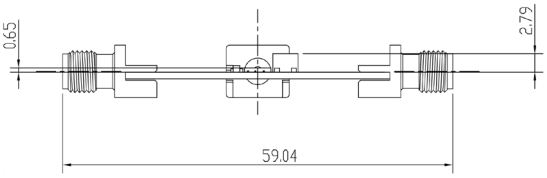
*MicroFB-SMA Board**











See Table 1 for connections.

** Schematics shown for 3mm versions. If the schematics for the other sizes are required then please contact support@sensl.com*

Handling and Soldering

Safe Handling of Sensors

- When unpacking, care should be taken to prevent dropping or misorienting the sensors. The specific items contained in the package and the type of packaging will depend on the parts ordered.
- Remember that the SiPM is a sensitive optoelectronic instrument; always handle the sensor as carefully as possible.
- The sensor should be disconnected from the bias supply when not in use.
- SiPM sensors are ESD sensitive. The following precautions are recommended:

  - Ensure that personal grounding, environmental controls and work surfaces are compliant with recommendations in JESD625.
  - Ensure that all personnel handling these devices are trained according to the recommendations in JESD625.
  - Devices must be placed in an ESD approved carrier during transport through an uncontrolled area.

Package Summary

Table 3 summarizes packages and product type. In the following sections, handling and soldering advice is given for each package type.

Package type	Product type	MSL*	Reflow Solder?
SMT - Tape & Reel	FB	3	Y
SMT - Cut Tape	FB	4	Y
SMT - Tray	FB	N/A	Y**
X18	FB	N/A	N
X13	SB	N/A	N

Table 3, Summary of which package types are associated with which product type.

**See Table 4 for definition*

*** Sensors shipped in a tray require a bake according to J-STD-20, prior to reflow soldering*

SMT Package

A dedicated SMT Handling and Soldering Tech Note is available that contains in depth information on the storage and use of the SMT parts, including the CAD for the tape and reels.

The SMT package is compatible with standard reflow solder processes (J-STD-20) and so is ideal for high volume manufacturing. The recommended solder footprints are shown in the Schematics section of this document. If the SMT part is being assembled into an array, the advice on page 11 and in the SMT Array Tech Note should be followed.

SMT SiPM sensors are shipped in moisture barrier bags (MBB) according to the J-STD 033 standard. An unopened MBB should be stored at a temperature below 40^{O}C with humidity below 90%RH. After the MBB has been opened, the devices must be reflow soldered within a period of time depending on the moisture sensitivity level (MSL). SensL SMT Tape & Reel are MSL 3, cut tape SMT are MSL 4 and SMT sensors shipped in trays require a bake prior to reflow soldering. See Table 4 for details.

MSL	Exposure time	Condition	Applicable SMT shipping format
3	168 hours	≤30 °C/60% RH	Tape and reel
4	72 hours	≤30 °C/60% RH	Cut tape and partial reels

Table 4, MSL definitions applicable to SensL products (reference J-STD 020).

All SMT shipped on tray do not have an MSL rating and should be baked prior to placement on PCB. Please discuss this with your contract manufacture for their recommended baking cycle which adheres to IPC/JEDEC J-STD-20 MSL Classification. Note the temperature of the bake should not exceed the recommended operating temperature of the product listed in product's datasheet.

The components are resilient to commonly used SMT flux cleaning detergents and Isopropyl Alcohol. It is important to allow the PCB to cool to room temperature after reflow and before flux cleaning in order to avoid excessive thermal shock.

Creating Arrays of SMT Sensors

If multiple SMT parts are to be mounted in close proximity (e.g. 1D or 2D arrays), the following recommendations may be helpful. By following this recommendations, a planarity of 0.09% to 0.53% can be achieved.

- Minimum spacing between SMT parts of 200μm.
- Use of FR4 PCB as the substrate material
- Use commercial automatic placement machines to achieve the necessary placement accuracy to give the above spacing and planarity.
- Take into account the MSL 3 specifications of the SMT devices when assembling.
- Hold the PCB board in a rigid frame to avoid warping due to the heat process.
- The user can refer to the additional Tech Note on this subject.

X18 Package

The X18 (TO-18 can) package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X18 products. A maximum temperature of **260°C for no more than 10 seconds** is recommended. More details can be found in the Hand Soldering Guide Tech Note.

X13 Package

The X13 ceramic package has through-hole pins and hand-soldering is recommended. The SiPM can be damaged by excessive heat and so it is important that due care be given to temperature and dwell time when soldering the X13 products. A maximum temperature of **260°C for no more than 5 seconds, applied at a distance of 2mm from the ceramic base** is recommended. More details can be found in the Hand Soldering Guide Tech Note.

'Not Connected' (NC) Pads and Pins

Common PCB design practice is to ground any floating pins or pads such as those labelled '*NC*'. Grounding the pin helps shielding and can reduce noise interference from external sources (EMI/RF).

Further Help

If more help is required in the set-up or operation of B-Series sensors, there are several SensL resources that can help.

• The B-Series Datasheet contains more detailed information on the physical and performance characteristics of the sensors.

• A variety of Tech Notes are available on the website, www.sensl.com, such as:

- A guide to handling and soldering SMT packages.
- A guide to hand soldering through-hole SensL sensor products.
- A guide on creating arrays of close-packed SMT sensors.
- An extensive library of technical and scientific papers on the use of SensL SiPM sensors.

• If additional help is needed, please contact support@sensl.com

Appendix A - Biasing Alternatives & Signal Polarity

This Appendix lists all of the possible ways in which a B-Series SiPM can be biased. Not all of them will deliver optimimum performance but are included for completeness. For each biasing arrangement, the *standard* and *fast* signal polarities are given. The following abbreviations are used throughout:

V_{bias} = bias voltage

Sout = standard output

Fout = fast output

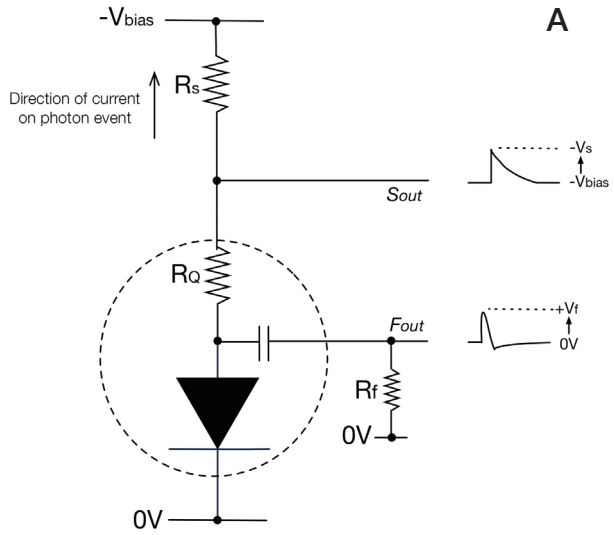
R_S = load resistor for the standard output

R_f = load resistor for the fast output

V_S = standard output voltage

V_f = fast output voltage

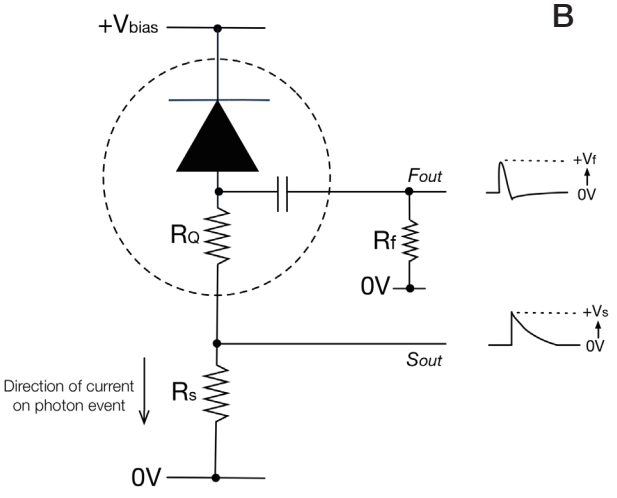
R_Q = quench resistor (included on the SiPM die)



When using one of the MicroFB products in fast mode, it is recommended to use biasing scheme A, as shown on the left.

This configuration will give the best timing performance and if fast output only is required then the resistor R_S can be zero ohms or -V_{bias} can be applied directly to the SiPM cathode.

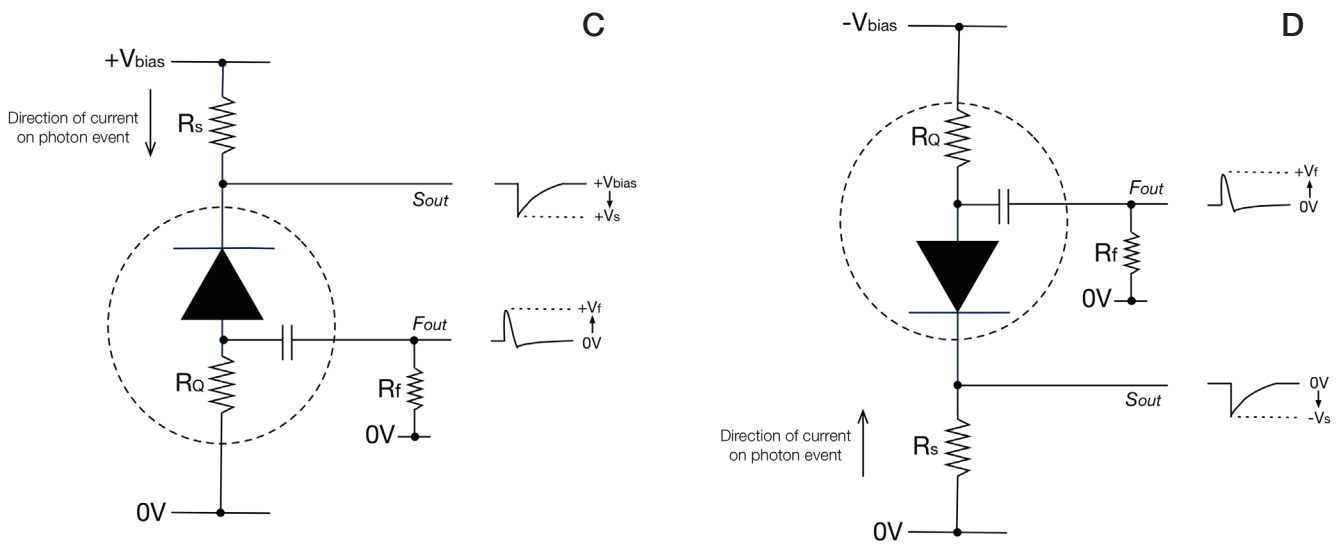
Note that there will be a negative offset on the *Sout* signal in this configuration as the pulse is referenced to -V_{bias}.



A positive bias can be applied to the cathode (substrate), as shown in B on the left, without any change in performance. However, care must be taken to ensure good decoupling of the bias voltage at the device since the substrate is the return path for the fast signal. If this biasing configuration is required, it is recommended that a 10nF (50V) ceramic SMT decoupling capacitor with low ESR is placed as close to the cathode as possible.

Without suitable decoupling the fast output pulse can suffer from ringing and pulse shape distortion when the positively biased cathode configuration is used.

An advantage of this configuration over configuration A is that the standard output is now referenced to 0V potential. However if the standard output is not required then the resistor R_S can again be made zero ohms or the SiPM anode connected directly to 0V.



Neither of the biasing schemes represented in C or D are recommended for use with high precision timing applications on the standard or in particular the fast output as these schemes would require the cathode substrate plane of the SiPM chip to be switched. However, either would be suitable for applications where the pulse timing is not critical.